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Satellite-Matrix-Switched, Time-Division-Multiple- Access Network Simulator

William D. Ivancic,
Monty Andro,
Lawrence A. Nagy,
James M. Budinger,
and Mary Jo Shalkhauser
*Lewis Research Center
Cleveland, Ohio*



National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Division

Summary

A versatile experimental Ka-band network simulator has been implemented at the NASA Lewis Research Center to demonstrate and evaluate a satellite-matrix-switched, time-division-multiple-access (SMS-TDMA) network and to evaluate future digital ground terminals and radiofrequency (RF) components. The simulator was implemented by using proof-of-concept RF components developed under NASA contracts and digital ground terminal and link simulation hardware developed at Lewis. This simulator provides many unique capabilities such as satellite range delay and variation simulation and rain fade simulation. All network parameters (e.g., signal-to-noise ratio, satellite range variation rate, burst density, and rain fade) are controlled and monitored by a central computer. The simulator is presently configured as a three-ground-terminal SMS-TDMA network.

Introduction

In 1978 NASA began a program to develop advanced communications satellite technologies. System studies performed during the late 1970's indicated that the Ku-band frequency spectrum would reach its capacity in the 1990's and that radio-frequency (RF) component and subsystem technology should be developed to utilize the Ka-band (30/20 GHz) spectrum. As a result, a number of Ka-band satellite communications architectures and their associated system technologies were studied at Lewis. In order to demonstrate a Ka-band satellite communications system with advanced technologies such as multibeam antennas, baseband processing, and satellite matrix switching, Lewis began developing an Advanced Communications Technology Satellite (ACTS), which is scheduled for launch in the early 1990's. Proof-of-concept (POC) subsystems and components including a baseband processor, intermediate-frequency (IF)¹ switch matrices, solid-state amplifiers, traveling-wave-tube, high-power amplifiers, and low-noise receivers were developed to prove technology and to enable flight models for the ACTS program. These devices have been integrated into a Ka-band satellite communications network simulation known as the Systems Integration, Test, and Evaluation (SITE) Facility (ref. 1). This facility is presently configured as a satellite-matrix-switched, time-division-multiple-access (SMS-TDMA) network simulator. This simulator, the network protocol, and the network experiments plan are described in this report.

The report has been organized in the following manner. First, background information is presented that explains the need for an SMS-TDMA network. Second, the actual ground terminal and RF hardware are briefly described. Third, the networking protocol and acquisition schemes are described. Fourth, the types of experiments that are presently being conducted on this simulator as well as planned experiments are summarized.

Background

Multibeam satellite communications architectures² are quite complicated because of overall network control and timing problems. Therefore, these architectures have been avoided when possible. Although it may not be immediately obvious, a multibeam or scanning beam communications architecture is necessary for systems operating at high frequency (i.e., 30/20 GHz).

A general understanding of the characteristics of antennas operating at Ka-band frequencies may help explain the need for such architectures. For simplicity the following explanation covers only parabolic antennas. In general it is applicable to other antenna configurations operating at these frequencies.

Two specific properties of parabolic antennas make multibeam satellite communications architectures possible. First, for any given-diameter parabolic antenna, as the frequency increases, the half-power beam width $\Delta\theta$ decreases. Conversely, for any given frequency, as the antenna diameter increases, $\Delta\theta$ decreases.

$$\Delta\theta \propto \frac{1}{fD}$$

where

f frequency

D antenna diameter

¹For this simulator, the IF is 3 to 6 GHz.

²A satellite communications system utilizing more than one uplink beam or more than one downlink beam. In this architecture the multiple uplink spot beams are generated by individual ground terminals and are received at the satellite by a single specially designed multibeam antenna. On the downlink the multiple spot beams are generated at the satellite and transmitted to individual ground terminals.

Second, for a circular aperture the antenna gain G increases proportionally to the square of the frequency.

$$G \propto f^2 D^2$$

Therefore an antenna designed to have sufficient gain to meet 30/20-GHz link requirements for satellites in geostationary orbit will have a diameter of approximately 1.5 to 4.5 m with individual spots approximately 50 to 200 miles in diameter.

In order for a satellite to cover the continental United States at Ka band with such an antenna, a multibeam or scanning beam communications architecture must be used. These architectures require a TDMA networking structure in order to fully utilize the satellite resources. For a nonprocessing satellite this architecture also requires a matrix switch. When multiple spot beams and a satellite matrix switch are used in a TDMA network, many ground terminals can communicate with one another at the same time, thus utilizing the satellite network to the greatest extent practical. Figure 1 depicts the data flow through an SMS-TDMA satellite.

SMS-TDMA Network Simulator

The SMS-TDMA network simulator consists of the following subsystems: three data generator/checker subsystems (DGCS), a master control terminal (MCT), two ground terminals, a network control computer (NCC), an experiment control and monitor (EC&M) computer, two range delay simulators (RDS), a digital routing processor (DRP), a power-processing unit (PPU), a matrix switch controller (MCS), an IF matrix switch, a rain fade simulator (RFS), up- and downconverters, high-power amplifiers (HPA), and low-noise receivers (LNR).

A block diagram of the digital portions of the SMS-TDMA communications simulator are shown in figure 2. The thin lines

between subsystems indicate hard-wired digital communications paths; the thick lines indicate microwave communications paths.

Data Generator/Checker Subsystem

Each data generator/checker subsystem (DGCS) simulates up to three separate users in the network and performs bit-error-rate (BER) measurements on individual communications links between the source and destination users.

The DGCS consists of a EC&M interface microcomputer and up to three data generator/data checker (DG/DC) units. (Reference 2 describes the DG/DC units in detail.) The EC&M interface microcomputer interconnects the EC&M computer, the ground terminal user interface controller (GTUIC), and the DG/DC's and acts as intelligent controller for the DG/DC's. The EC&M interface microcomputer processor interprets commands from the EC&M computer to control the DG/DC's, sends status and BER data back to the EC&M computer, transmits user access requests to the network through the GTUIC, and transmits DG/DC status to the GTUIC. The data generator portion of each DG/DC transmits a user clock and data source to the ground terminal. The data checker portion of the DG/DC receives clock and data signals from the ground terminal. The DG/DC can transmit and receive pseudorandom data at a variety of data rates from 1 to 200 MHz. Each DG/DC consists of an independent data generator and data checker; thus any data generator may communicate with any data checker in the network so long as the generator and checker are operating at the same data rate.

Figure 3 shows a generalized block diagram of the DGCS, a traffic ground terminal, the interface between the DGCS and the EC&M computer, and the interface between the DGCS and a ground terminal.

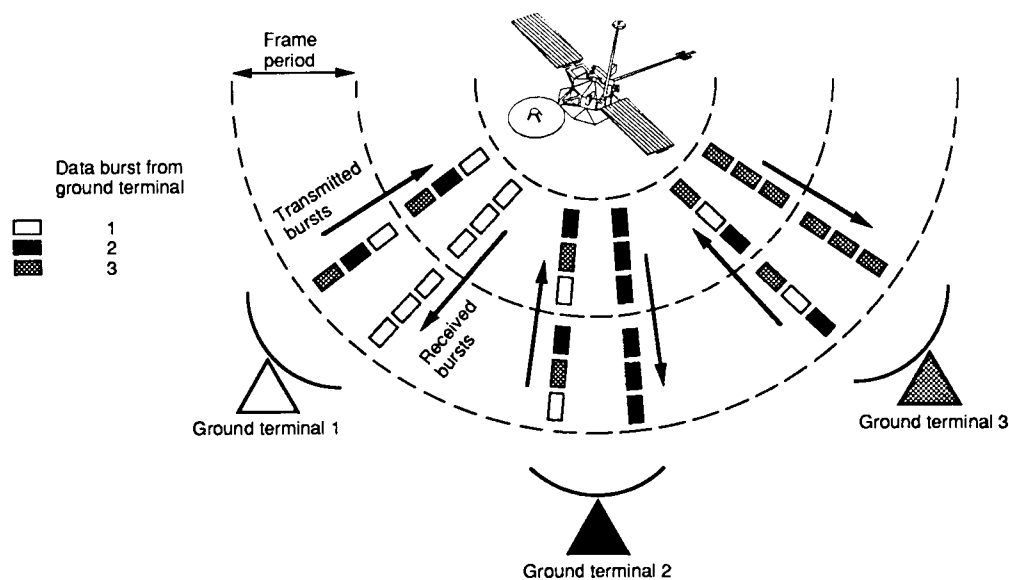


Figure 1.—Satellite-matrix-switched, time-division-multiple-access (SMS-TDMA) network.

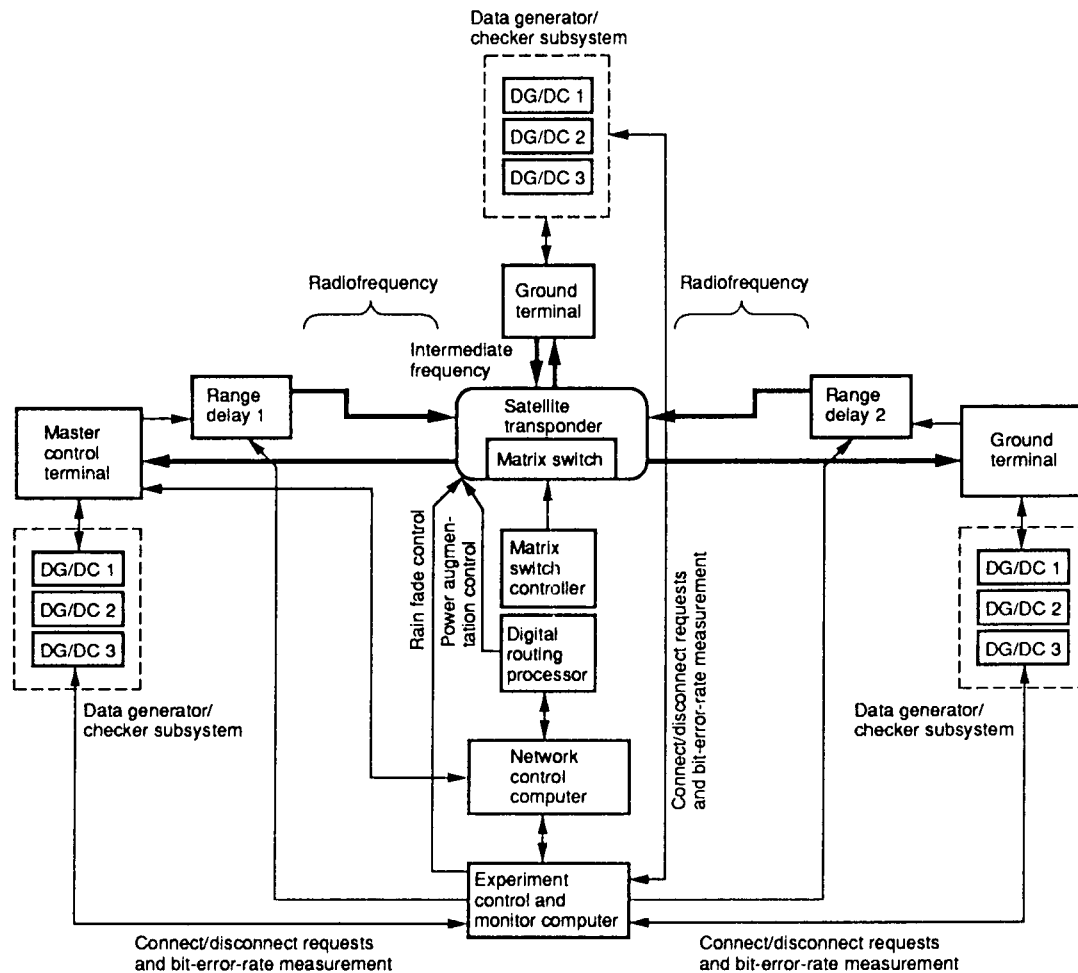


Figure 2.—Block diagram of SMS-TDMA network simulator.

Ground Terminals

The ground terminal is a major element of the simulator and one of the more complex. Each ground terminal must be capable of acquiring satellite and network timing, maintaining synchronization to the network, and transmitting and receiving bursted data from other ground terminals in the network.

Each ground terminal contains a 221.184-MHz system clock, transmission and reception timing and control circuits, compression or expansion first-in, first-out memories (FIFO), separate user clocks and their associated control circuits, an orderwire processor microcomputer, a user interface controller, and a 221.184-MHz serial minimum-shift key (SMSK) burst modulator/demodulator (modem).

Each ground terminal has a 221.184-MHz oscillator with a short-term stability of 5×10^{-11} per second and an aging stability of 3×10^{-8} per day. All ground terminal transmission and reception timing is based on this oscillator.

The transmission and reception timing and control circuits serve to establish and maintain synchronization with the net-

work. Included in this circuitry are transmission and reception frame and superframe counters and two word-clock prescaling circuits. The clock prescaling circuits shift the transmission or reception word clock by plus or minus one bit time, thus changing the effective oscillator frequency on either the transmission or reception portion of the ground terminal. This bit insertion or deletion is done to compensate for oscillator drift and path delay variation due to satellite motion.

The compression and expansion FIFO's are used as buffers to adjust for the transmission-side and reception-side users' timing differences and to compensate for clock instabilities and Doppler frequency shifts induced by satellite motion. On the transmission side compression FIFO's convert continuous, serial, lower rate user data (i.e., 1 to 200 MHz) into higher rate data bursts (i.e., 221.184 MHz) for transmission through the modulator. On the reception side bursts of data recovered by the demodulator are expanded back into continuous serial data through the expansion FIFO for delivery to the destination user.

Reception-side user clocks are recreated by voltage-controlled oscillators that are continuously adjusted so that the

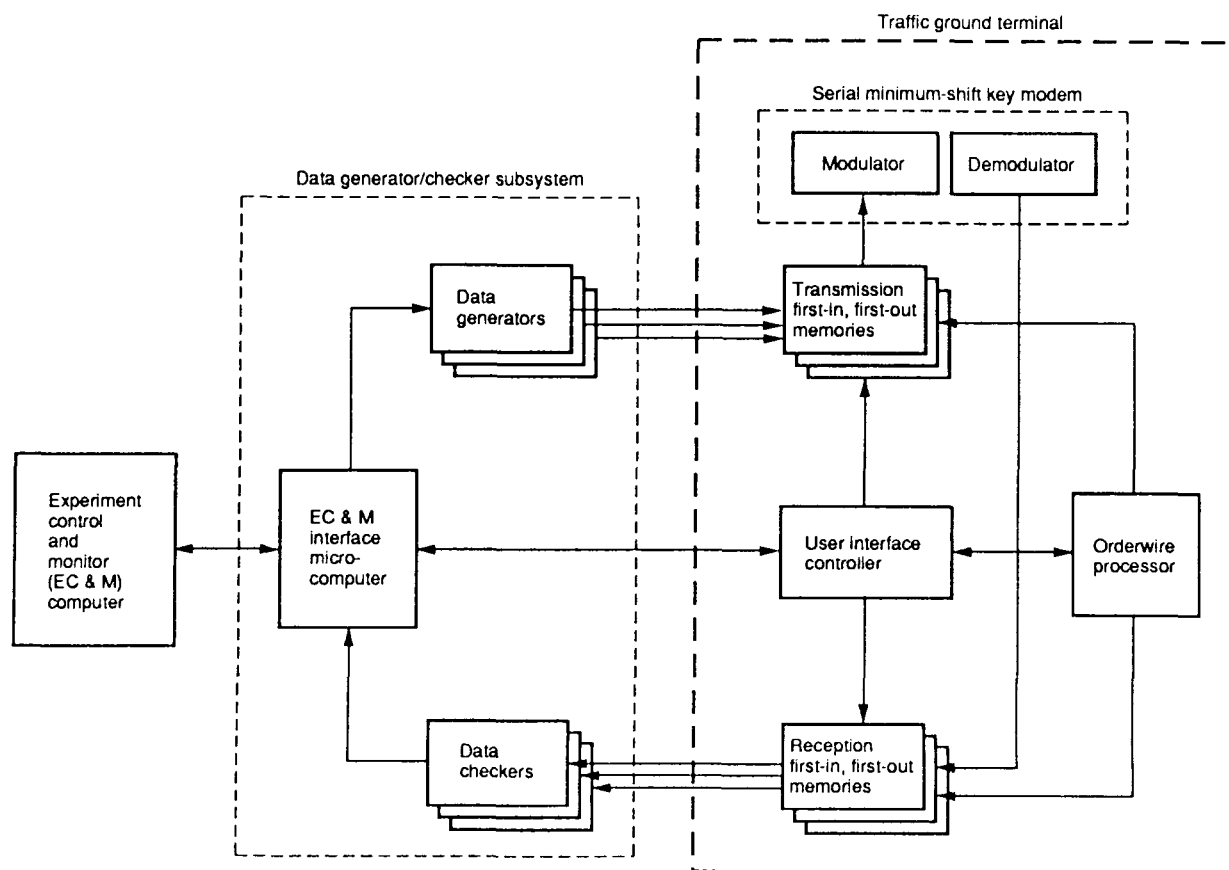


Figure 3.—Interface between experiment control and monitor computer, data generator/checker subsystem, and ground terminal.

ground terminal's reception-side expansion FIFO's never empty or overflow. These data clocks are generated in the reception-side portion of the ground terminal and transmitted to the data checker portion of the DG/DC.

The orderwire processor is a 68000-based microcomputer. Its functions are to monitor user requests for connection, request user connections into the network through the in-band orderwire, monitor all reference burst communications from the MCT, and control all ground terminal transmission and reception timing.

The user interface controller monitors the status of the DGCS, passes new valid connect or disconnect requests from the DGCS to the orderwire processor, passes request granted or denied information to the DGCS from the orderwire processor, and provides the appropriate control signals to the DGCS to operate individual data generators and data checkers.

The SMSK burst modems are critical to the overall network design and operation. The operational characteristics of the modem determine to a large degree how network timing and acquisition are performed as well as the burst formats. The SMSK modems developed by Motorola can operate at two data rates (221.184 and 110.592 Mbps). They can accommodate a 20-dB burst-to-burst variation with a ± 30 -kHz burst-to-burst input frequency offset and as much as ± 60 ns of burst arrival time uncertainty, all within a 256-symbol preamble.

The SMSK modulator receives a clock and data and outputs an SMSK-modulated IF carrier. The modulator on/off bursting is controlled by an RF³ switch at its output. The SMSK demodulator receives a modulated SMSK carrier and outputs a synchronized clock, data, and a signal indicating the start of valid data.

Master Control Terminal

The master control terminal (MCT) is identical to a traffic ground terminal except that it has an additional microcomputer and associated software. In addition to performing as a normal traffic ground terminal, the MCT communicates with the NCC to control the communications network, brings new ground terminals into the network via reference burst, and monitors orderwires for connection and disconnection requests.

Network Control Computer

The network control computer (NCC), a minicomputer, receives network status from the MCT, executes traffic-routing algorithms to optimize the network, and controls the satellite power and matrix switch through telemetry, tracking, and

³For this simulator the RF is 18 to 30 GHz.

control (TT&C) commands to the DRP. In the SITE facility the NCC interfaces with both the MCT and the DRP through an RS-232 interface. In an actual system the NCC/DRP TT&C interface would be through a low-data-rate RF channel.

Range Delay Simulator

A range delay simulation is required to test acquisition and synchronization of the ground terminals. In an actual satellite communications system each ground terminal will "see" a different aspect of the satellite's tidal and stationkeeping motion and hence experience a different variation in range delay. As a result each ground terminal must constantly adjust its transmission burst timing so that data bursts from separate terminals arrive at the satellite in their designated time slots to keep the system in synchronism. On the receiving end ground terminals must individually synchronize their timing with bursts received from the satellite downlink.

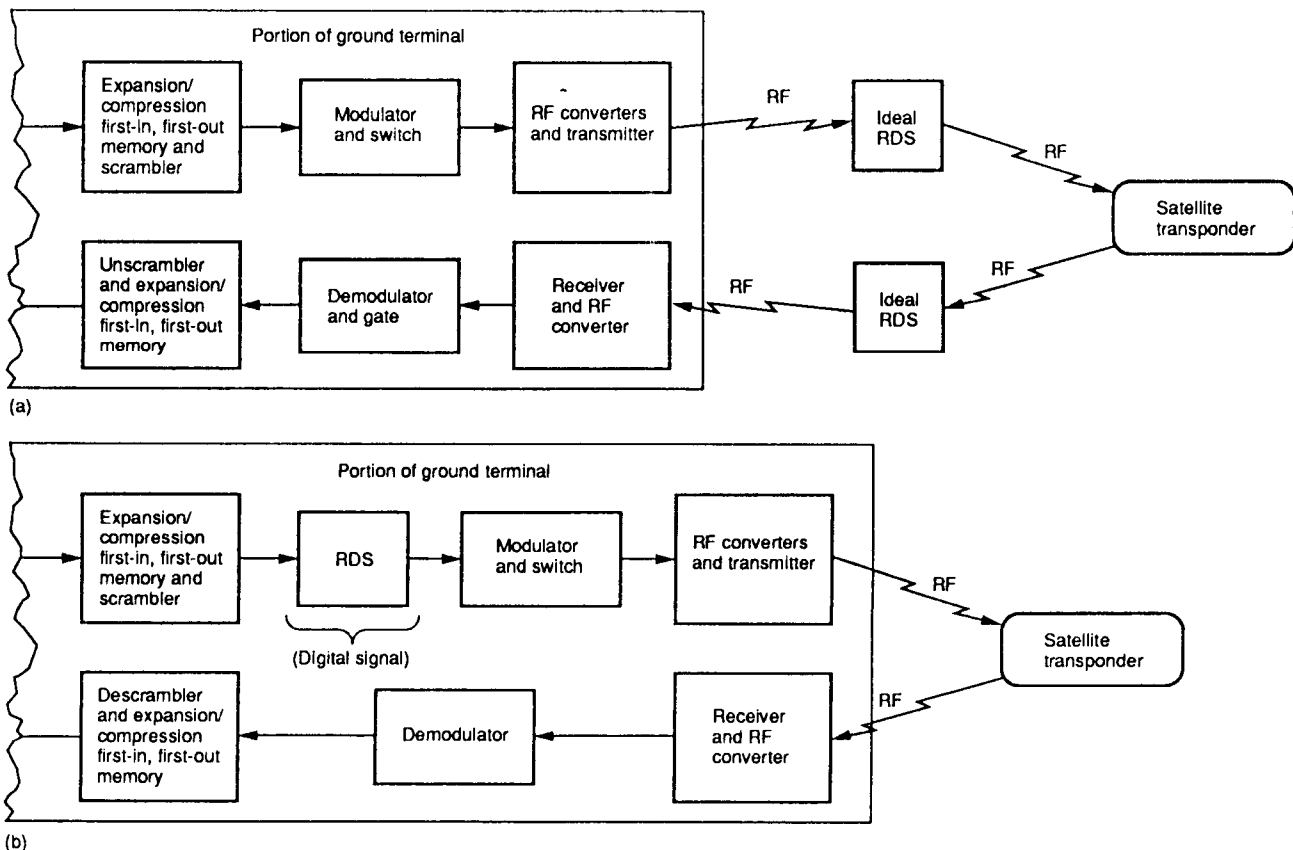
The range delay simulator (RDS) can provide a controlled variable time delay exceeding full geosynchronous orbit delay (119 ms) with a range variation rate as high as 339 m/s, more than 100 times greater than that of a typical satellite. The heart of the RDS is a large array of dynamic random-access memory (DRAM) integrated circuits configured as a FIFO. By reading

the data out of the FIFO at a preset delay interval and a slightly different clock rate than it was written in (at the ground terminal's clock rate), a changing delay and simulated Doppler frequency shift are achieved.

The RDS takes 64-bit parallel data along with timing information from the ground terminal, delays it, converts the data to a bursted serial stream, and outputs the serial data along with a burst control signal to the ground terminal's modulator and RF switch. The RDS may be controlled by either the EC&M computer or the front panel switches. No control signals are initiated from the ground terminal.

Inserting delay upstream of the modulator to simulate satellite range delay deviates from an actual satellite link, where the delay is in the RF path. Obviously, an ideal range delay simulation would be to duplicate the delay in the RF path between the ground terminal transmitter and the satellite. For a laboratory simulation of full variable range delay, however, the use of digital semiconductor memory is the most practical and cost-effective solution available. Accordingly, the RDS operates on the uplink baseband signal prior to modulation (fig. 4).

On the downlink side, however, the constraint of the RDS to operate on a digital signal would require that it be inserted



(a) Ideal range delay simulation (in radiofrequency link).

(b) SITE facility implementation of range delay simulation.

Figure 4.—Ideal and practical implementation of range delay simulator (RDS).

downstream of the receiving ground terminal's demodulator, artificially complicating the ground terminal control of the demodulator. Consequently, only uplink RDS's are implemented. They serve to test the timing functions in both the receiving ground terminal and the transmitting ground terminal in a network simulation with a non-signal-processing satellite.

Experiment Control and Monitor Computer

The EC&M computer monitors and controls all test equipment, creates environmental disturbances to the RF channel, and stimulates communications traffic flow (ref. 3). The ability of the EC&M computer to adjust and monitor the link parameters allows a large variety of tests to be performed quickly and accurately. The RF parameters are adjusted by using attenuators and monitored through power meters—all under EC&M computer control. Through the use of attenuators and power meters the EC&M computer can accurately vary the signal-to-noise (S/N) parameters as well as simulate rain fade. The EC&M computer controls the RDS to simulate satellite motion and monitors the RDS to ensure accurate range delay and variations. The EC&M computer also controls the DG/DC's that simulate user traffic on the network and monitors the DG/DC's to determine bit error rate through any possible microwave communications channel.

Matrix Switch

Two matrix switches were developed for NASA: a 20-by-20 matrix switch by General Electric Aerospace (ref. 4) and a 22-by-22 coupled-crossbar matrix switch by Ford Aerospace (ref. 5). The Ford matrix switch was selected for use in this simulated transponder. Only a portion of the crosspoints are actually populated. The switch is constructed so that a broadcast mode is available; thus any input can be connected with all outputs at the same time. The switch is also constructed so that only one output may be connected to one input at any instant. The average switching time of the Ford switch is 15.6 ns (ref. 6). In the present system only a 3-by-3 matrix switch is required; therefore only a small portion of the Ford switch will be utilized.

Matrix Switch Controller

The matrix switch controller (MSC) provides an interface between the digital routing processor and the matrix switch. It receives matrix switch updates from the DRP and provides matrix switch status to the DRP. The MSC controls the IF matrix switch crosspoints, on/off conditions, and switching times.

The MSC consists of two large memory blocks: an on-line memory block that determines the current matrix switch configuration, and an off-line memory block that is updated by the DRP to establish the next matrix switch configuration. When the off-line memory update is complete, the DRP will switch the memory blocks in synchronism with network superframe timing, thus reconfiguring the switch. The MSC

is capable of controlling up to a 22-by-22 matrix switch with each matrix switch crosspoint activated through individual transistor-transistor logic (TTL) control lines.

Because the MSC controls the satellite switching and because all network timing is referenced to the satellite switching, the MSC uses an extremely stable oscillator with a 3×10^{-11} -per-second short-term stability and a 1×10^{-9} -per-day aging stability.

Digital Routing Processor

The digital routing processor (DRP) provides the intelligence to the MSC and the power-processing unit (PPU). The DRP receives commands and matrix switch updates from the NCC, relays the updates from the NCC to the MSC, determines when the MSC should reconfigure the matrix switch, and reads the matrix switch configuration from the MSC for relay back to the NCC. The DRP also controls the power mode and gain control attenuator on the PPU and transmits satellite amplifier power status back to the NCC. The DRP is considered part of the satellite bus.

Power-Processing Unit

The power-processing unit (PPU) controls and monitors the traveling-wave tube amplifier (TWTA) power. It interfaces with both the DRP and the TWTA.

Rain Fade Simulator

Attenuation of Ka-band RF signals due to rain (rain fade) is extremely high. A satellite system operating at this band must dynamically compensate for these attenuations with a power augmentation scheme. The rain fade simulator (RFS) provides the capability to test this process. In the present network simulator rain fade will only be simulated on the downlink and will be compensated for by increasing the satellite transmitting power. Future simulator configurations may allow for adaptive coding to be inserted into the specific link experiencing a fade.

The RFS is implemented by using a pin diode attenuator having a 0- to 25-dB attenuation range over a 0- to 5-V input voltage range. This attenuator has excellent precision, accuracy, and speed characteristics. The pin diode voltage is provided by a power supply controlled by the EC&M computer.

RF Communications Channels

There are three active channels in the present SMS setup: two RF channels and an IF channel.

Two of the three channels are nearly identical and are configured for link experiments. In these two links the baseband data are SMSK modulated to an IF of 3.373 GHz and upconverted to approximately 30 GHz. The RF signal is then attenuated to a level acceptable to the low-noise receiver by using a variable attenuator. The LNR amplifies and downconverts the RF signal, which is then passed through the IF

matrix switch. The IF output signal of the matrix switch is upconverted to approximately 20 GHz and amplified through a high-power amplifier (either a solid-state amplifier or a TWT). Next, the RF signal is attenuated, mixed down to 3.373 GHz, and demodulated (fig. 5).

The second channel may be used as either a local or a remote channel (fig. 6). The remote link uses a 2.44-m-diameter dish antenna at the ground terminal and horn antennas at the transponder. This link is useful for conducting actual rain fade experiments, other experiments involving atmospheric effects on the RF signals, and adjacent and cochannel interference experiments. The remote link is discussed in detail in reference 7.

The third channel, the IF channel, is available for network experiments only. In the third channel the baseband data are SMSK modulated to an IF of 3.373 GHz. This signal is then upconverted to the IF frequency band of the matrix switch, 3.7 to 6.2 GHz, and its gain is adjusted to an acceptable level for the matrix switch. The output signal of the switch is downconverted to 3.373 GHz and demodulated (fig. 7).

SMS-TDMA Network Timing and Protocol

The simulated SMS-TDMA network consists of three ground terminals linked together by three channels of the 22-by-22 matrix switch. One of the ground terminals serves as the MCT and controls the network. This section describes the network timing and network communications protocol.

SMS-TDMA Network Timing

All network timing is derived from the 221.184-MHz data burst rate clock of the MCT, which is synchronized with the

satellite matrix switch clock. Words, frames, and superframes are composed of integer multiples of the data burst rate clock (table I). The serial data bit stream is grouped into 64-bit words in order to process parallel data at a rate compatible with transistor-transistor logic and because the 64-bit word is a terrestrial telecommunications standard (i.e., there are 64 bits in a digital system level zero (DS0) channel). A subframe consists of eight words; a frame consists of 864 words, or 108 subframes; and a superframe consists of 5000 frames. Bits and words are used for ground terminal timing; frames and superframes are used for network timing. The fundamental timing unit of the TDMA network is the frame.

SMS-TDMA Network Communications

Each frame contains a number of bursts that may vary in length. The first four words of every burst make up the preamble required by the SMSK demodulators. All network communications between ground terminals are accomplished by using in-band communications (i.e., control and status commands reside in the same communications channel as data transmissions) and one of four types of bursts: metering, reference, orderwire, or data.

Metering bursts.—Metering bursts are used by the MCT to acquire the satellite “frame” timing. A metering burst may be many words long. The first four words, the preamble, are followed by an integer number of words consisting of a fixed binary pattern (fig. 8). The NCC via the MCT compares the transmitted pattern with the received pattern to determine the necessary timing adjustments that the MCT must make in order to synchronize the MCT’s timing to the satellite’s timing.

Reference bursts.—Reference bursts are used for network timing and control. All reference bursts originate at the MCT. The reference burst is always located at the beginning of each

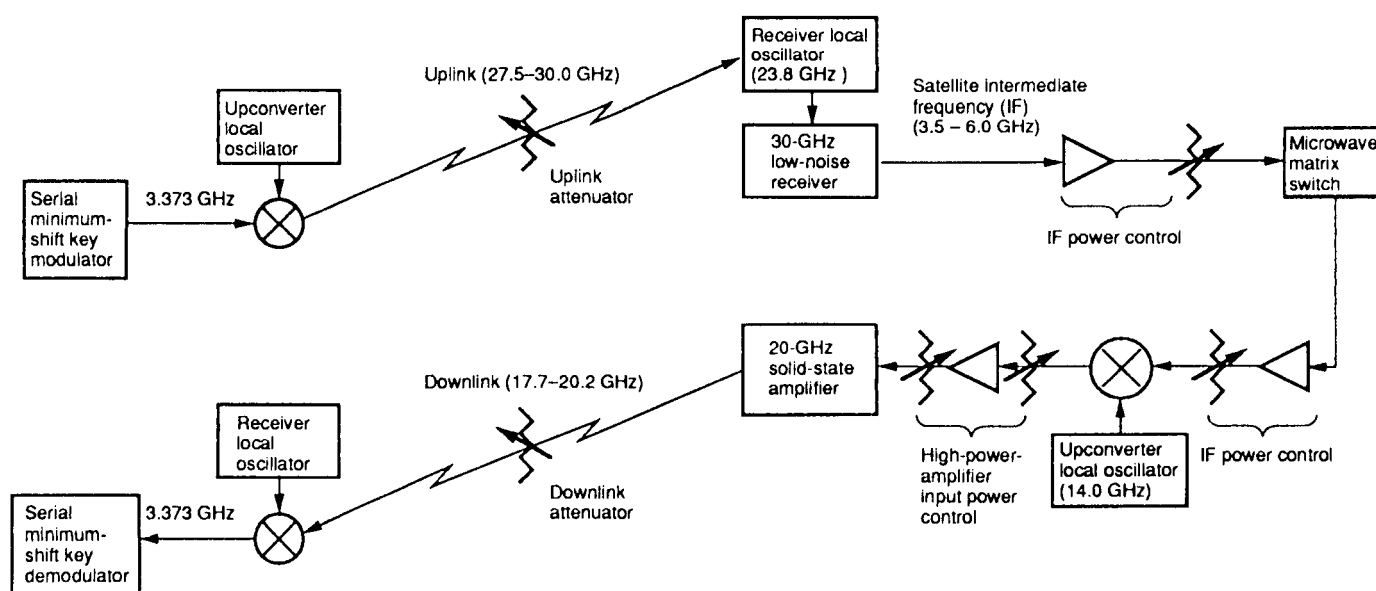


Figure 5.—Radiofrequency link for ground terminal 1.

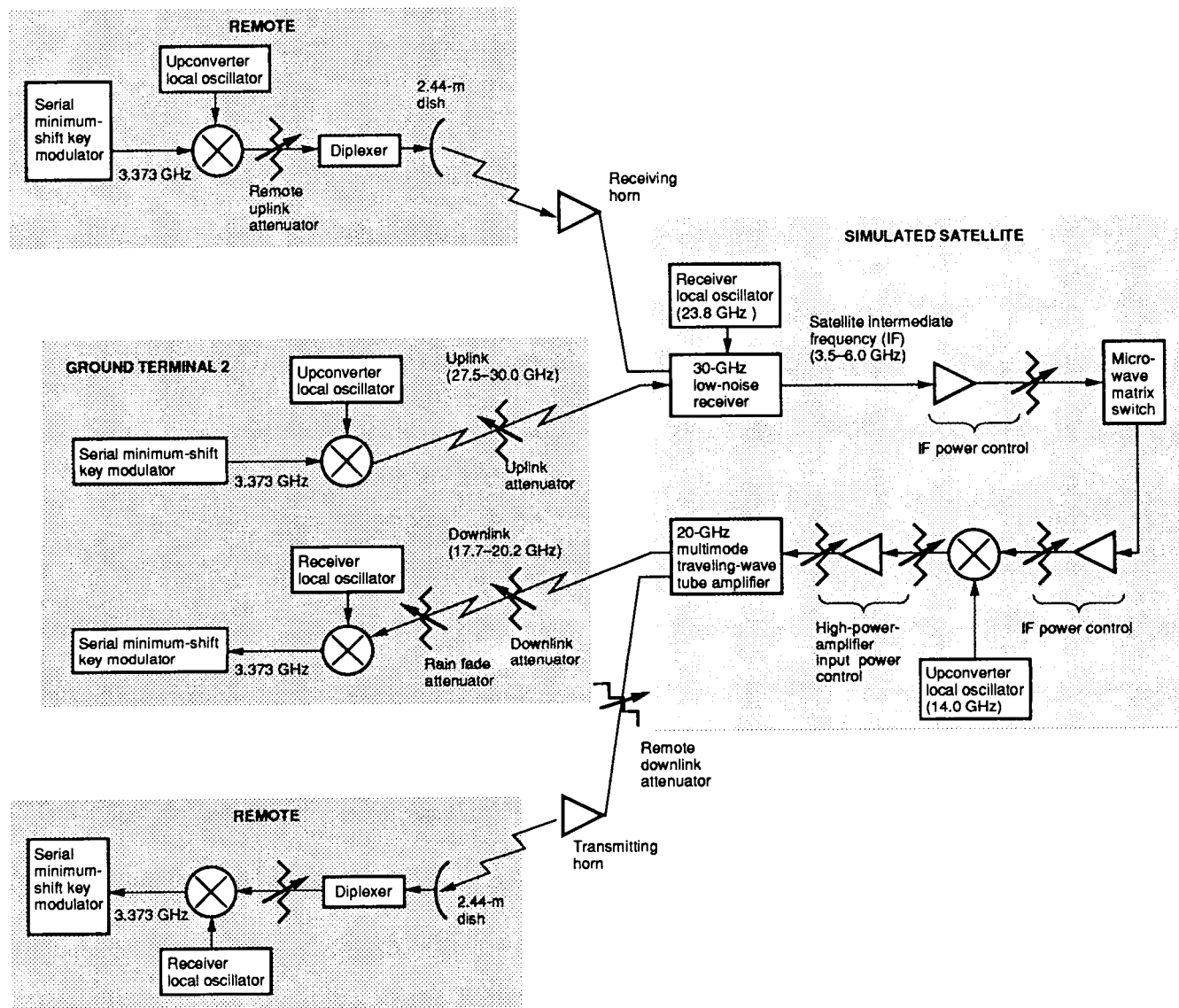


Figure 6.—Radiofrequency link for ground terminal 2 and remote ground terminal.

frame at word location zero. Each reference burst is five words long, four words of preamble and one word of timing and control information. The timing and control information is heavily encoded for error detection by using a 16-bit cyclical redundancy code (CRC).

There are seven types of reference burst commands: superframe synchronization, ground terminal synchronization, move, status, reception connections, transmission connections, and null. The timing and control information word in all reference bursts except the superframe synchronization burst have the following three fields: burst type, destination terminal address, and reference burst type. The burst type field indicates that the burst is a reference burst; the destination terminal address field contains the address of the ground terminal to which the reference message is directed; and the reference burst type field determines the structure of the reference burst.

The superframe synchronization burst is used by all ground terminals to synchronize their reception-side circuitry to superframe timing. The superframe synchronization burst is easy to recognize because bits 48 to 63 are zero (fig. 9).

The ground terminal synchronization burst is used to synchronize transmission burst timing. This burst contains three unique fields: loopback subframe location, transmission/reception frame offset, and transmission/reception word offset. The loopback subframe location indicates the subframe location of this received burst. The frame and word offset fields give an estimation of roundtrip satellite delay (fig. 10).

The move reference burst contains four unique fields: old burst subframe location, new burst subframe location, reception burst move, and transmission burst move. The two burst subframe location fields indicate the burst's old (present) location and the location that the burst will be moved to. The

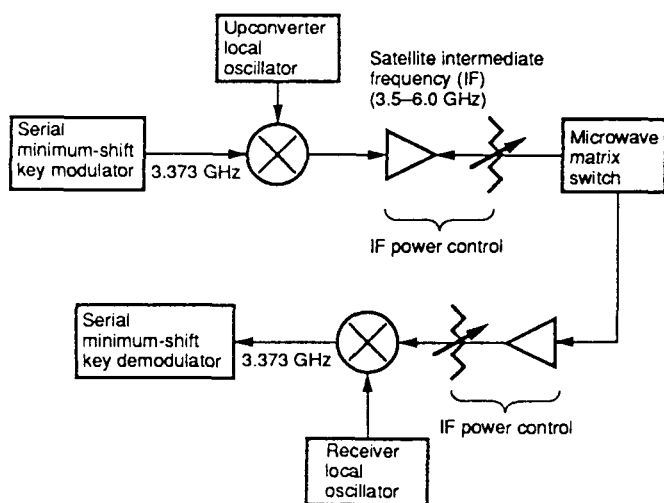


Figure 7.—Intermediate-frequency link for network experiments.

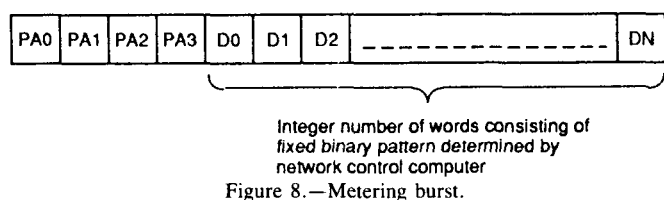


Figure 8.—Metering burst.

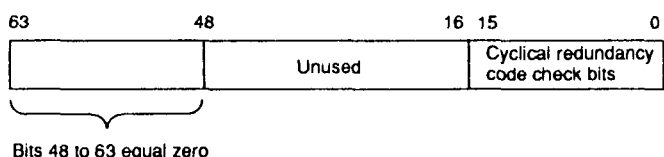


Figure 9.—Reference burst—superframe synchronization command.

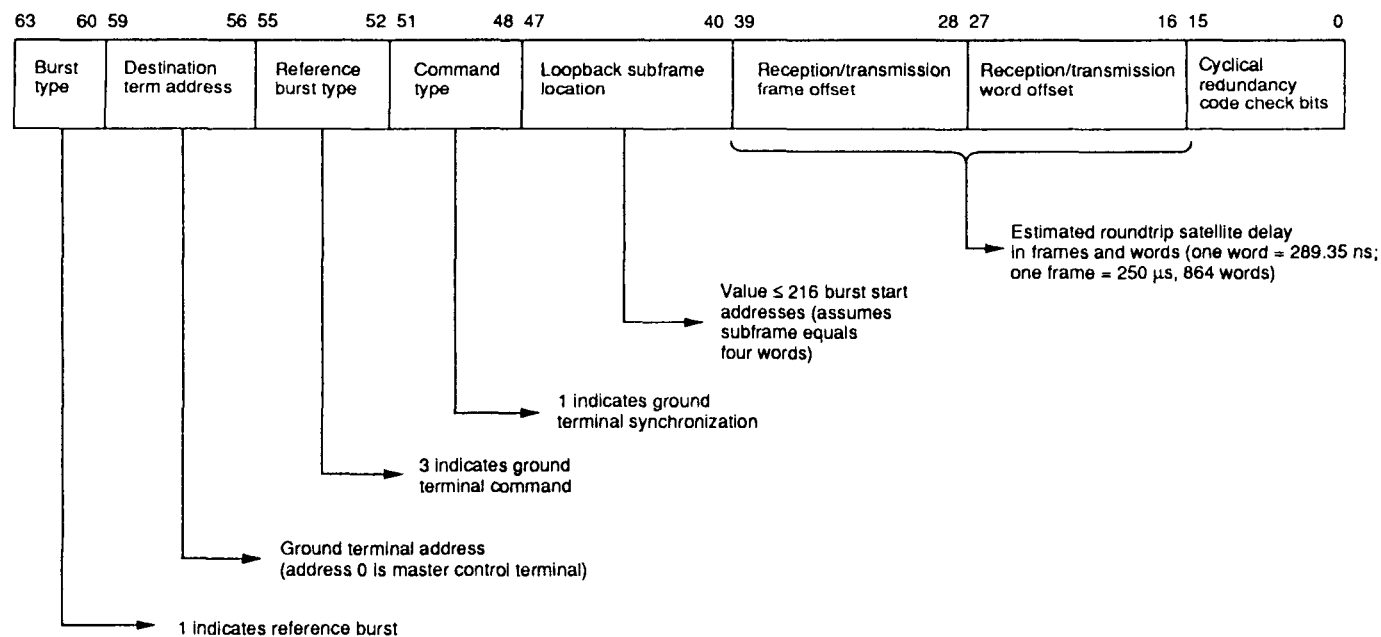


Figure 10.—Reference burst—ground terminal synchronization command.

TABLE I.—NETWORK TIMING CONVENTIONS

| | Rate | Time | Bits | Words | Frames |
|------------|-------------|------------|--------------------------|-----------------------|--------|
| Bit | 221.184 MHz | 4.521 ns | 1 | ----- | ---- |
| Word | 3.456 MHz | 289.352 ns | 64 | 1 | ---- |
| Subframe | 432 kHz | 2.314 μs | 512 | 8 | ---- |
| Frame | 4 kHz | 250 μs | 55 296 | 864 | 1 |
| Superframe | 0.8 Hz | 1.25 s | 27 648 × 10 ⁴ | 432 × 10 ⁴ | 5000 |

two burst move fields dictate whether a transmission burst, a reception burst, or both are to be moved (fig. 11).

The status request reference burst prompts the specified ground terminal to respond with its measure of the roundtrip delay for that ground terminal (fig. 12).

Both the reception connection reference burst and the transmission connection reference burst have the following six fields: user number, burst length, starting subframe number, valid or nonvalid word count (vwc/nvwc), simplex/duplex, and disconnection/connection denied. The user number indicates which one of three DG/DC's will be accessed—data generators on the source terminals for transmission connections and data checkers on the destination terminal for reception connections. The burst length gives the length of the burst in number of words. The starting subframe number indicates the location of the burst in the frame. The vwc/nvwc field indicates whether or not a valid word count is used. This field will be explained in the data burst discussion. The simplex/duplex field indicates whether the connection will be one way or two way, and the disconnection/connection denied field indicates whether the circuit connection request is granted or denied (figs. 13 and 14).

The null reference burst is transmitted in the reference burst location when no new command or control information is

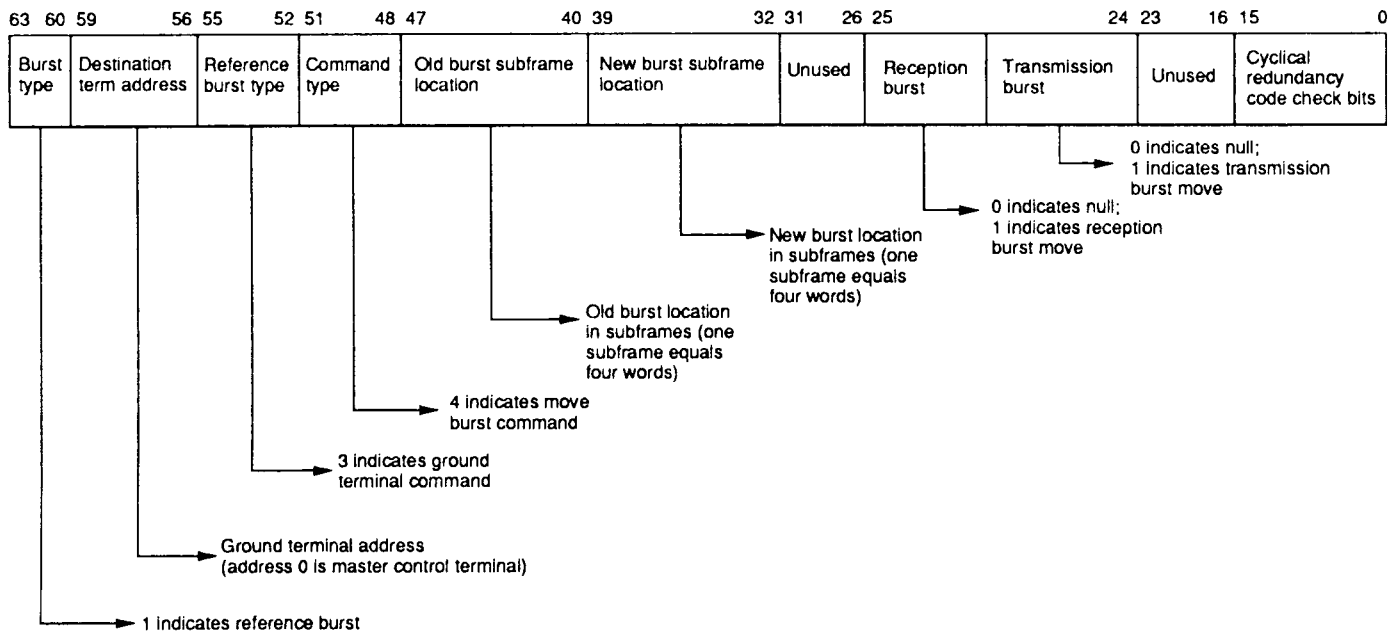


Figure 11.—Reference burst—move burst command.

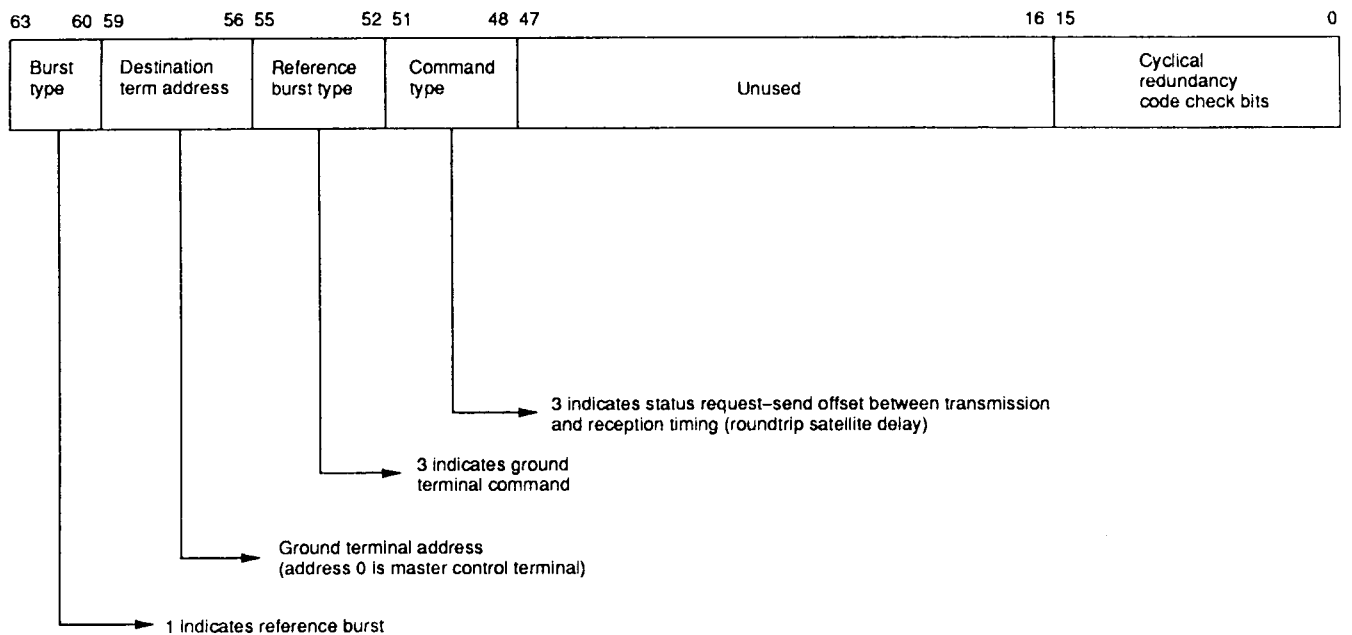


Figure 12.—Reference burst—status request command.

required by the network. The null reference burst contains an address to a specified terminal but no usable information (fig. 15).

Orderwire bursts.—Orderwire bursts are used by ground terminals to request connections and disconnections to and from the network and to transmit ground terminal status to the MCT. Orderwire bursts originate at the traffic ground terminals and may be located anywhere in a frame, with the specific location determined by the MCT. Like the reference

burst, each orderwire burst is five words long with the first four words being preamble and the last word containing timing, control, or status information. Again, the fifth word is heavily error detection encoded by using a 16-bit cyclical redundancy code.

There are five types of orderwire bursts: simplex connect/disconnect, duplex connect/disconnect, power augmentation request, transmission/reception offset status, and null request. All orderwire bursts have the following three fields: burst type,

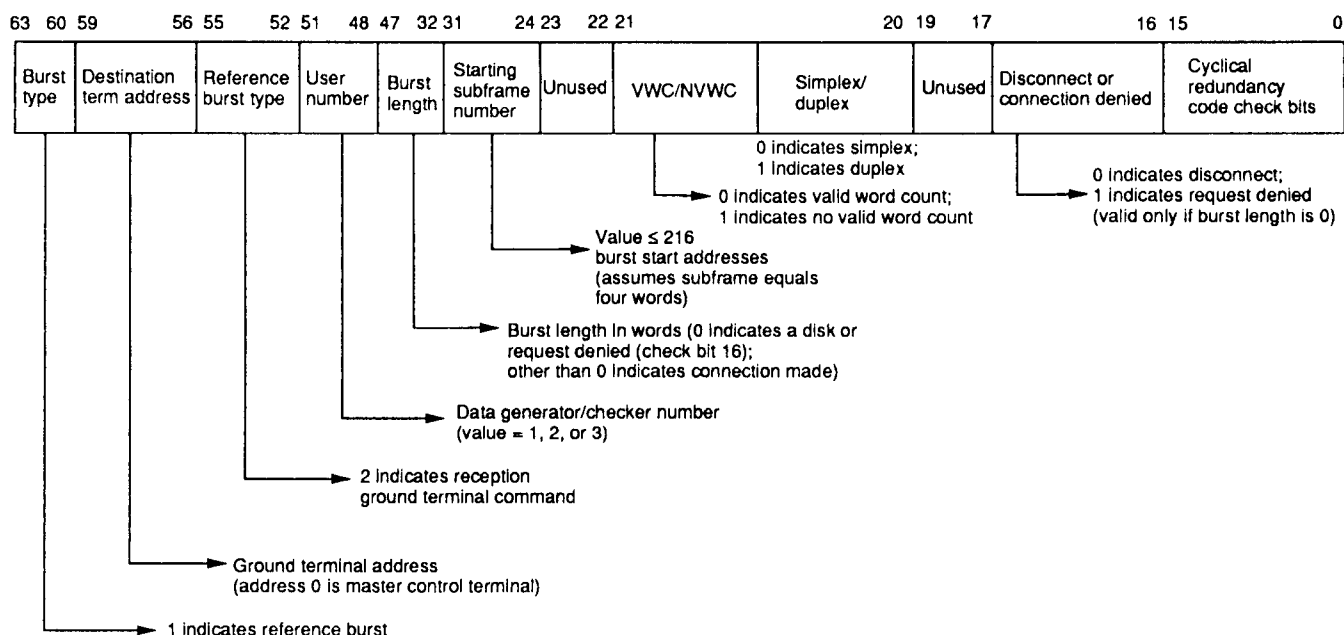


Figure 13.—Reference burst—reception connection type command.

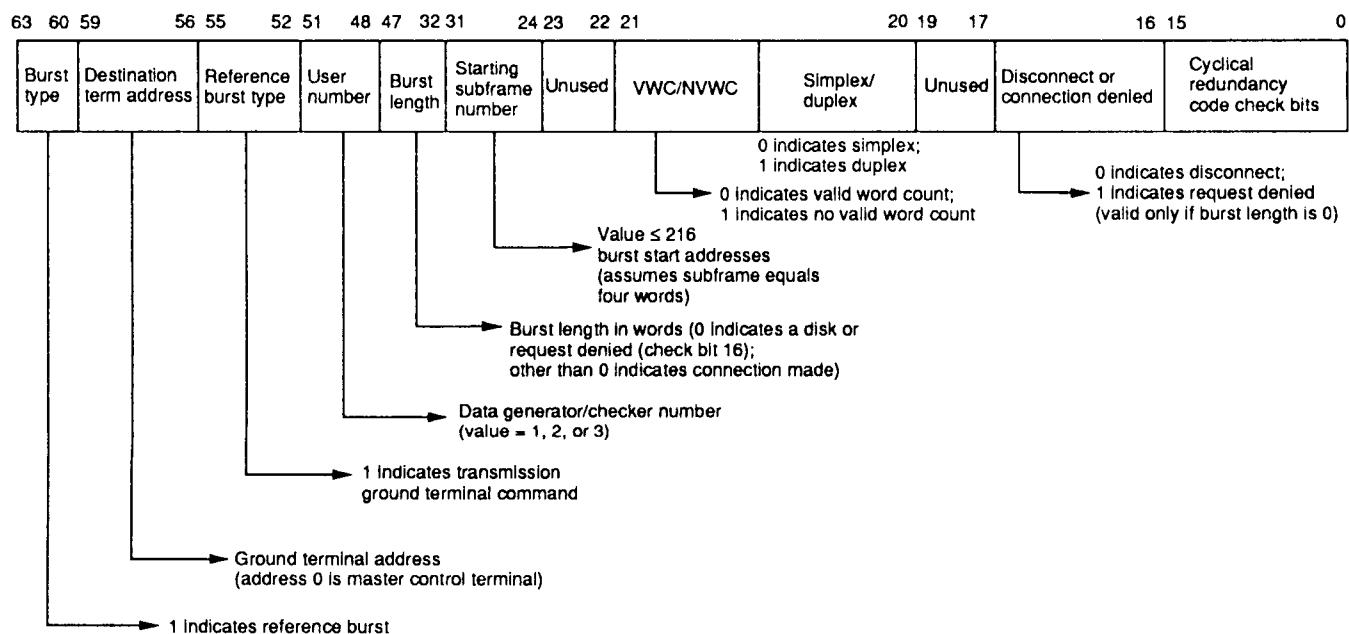


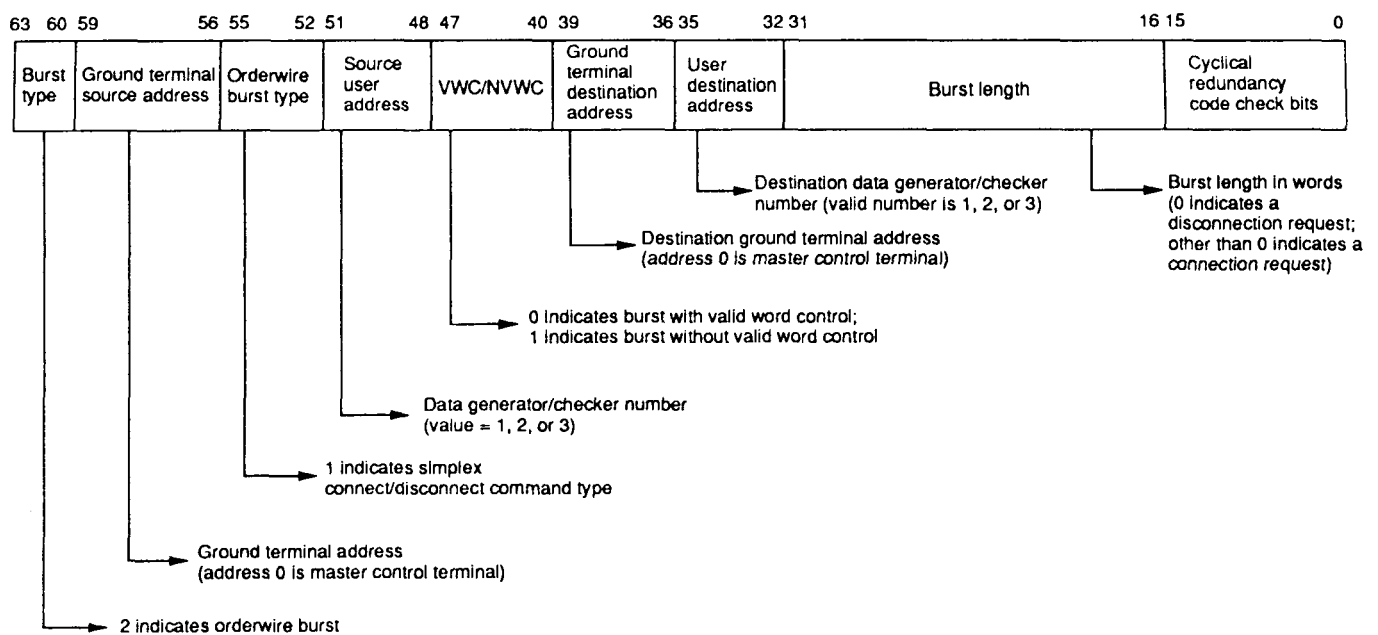
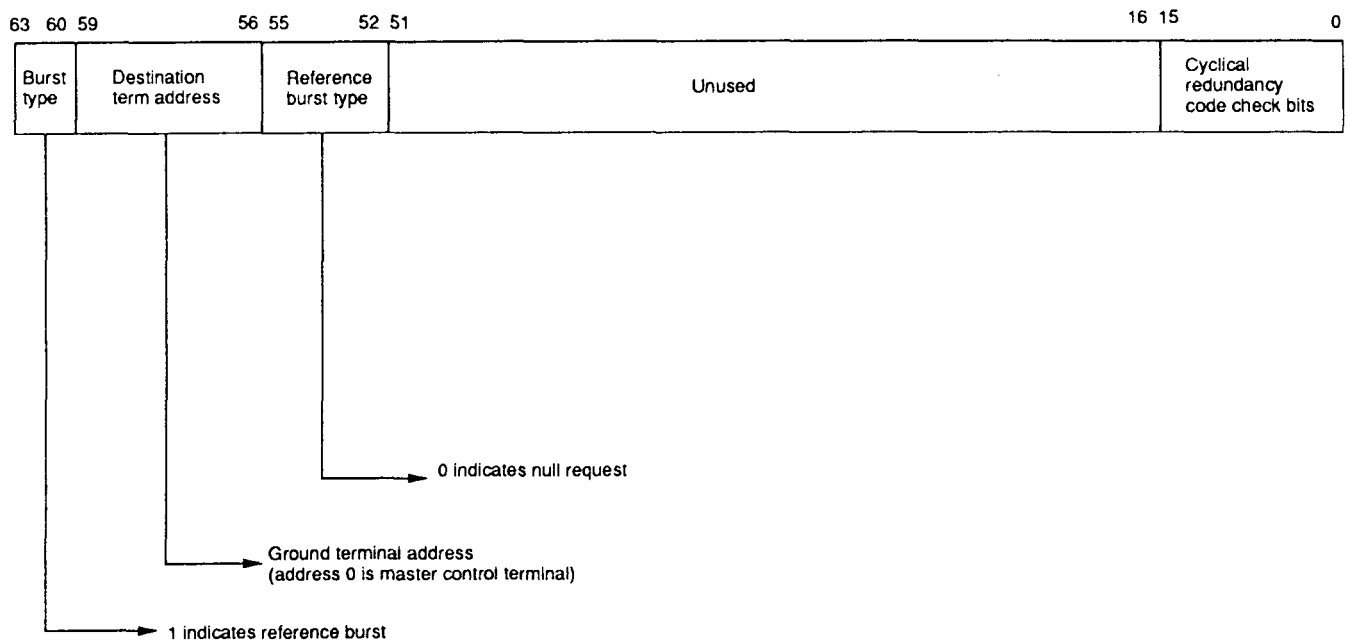
Figure 14.—Reference burst—transmission connection type command.

source ground terminal address, and orderwire burst type. This time the burst type field indicates that the burst is an orderwire burst, the source ground terminal address field contains the address of the ground terminal from which the message originates, and the burst type field determines the structure of the orderwire burst.

Both the simplex connect/disconnect and duplex connect/disconnect orderwire formats contain the following unique fields: source user address, vwc/nvwc, ground terminal destination, user destination, and burst length. The source user address field

indicates which DG/DC is to be connected to the network as the data source. The vwc/nvwc field indicates a request to burst with or without a valid word count. The ground terminal destination field contains the address of the destination ground terminal to which the connection is requested. The user destination field contains the address of the source ground terminal. The burst length field contains the requested channel capacity in number of words (i.e., burst length) (figs. 16 and 17).

The power augmentation request orderwire is used to request that the MCT increase or decrease the satellite downlink power



to that specific ground terminal. Only one unique field is necessary to transmit this request (fig. 18).

The transmission/reception offset status orderwire is used to transmit the ground terminal's roundtrip satellite delay information to the MCT. There are three unique fields in this orderwire: frame offset, word offset, and bit offset. The roundtrip satellite delay measurement is expressed as the frame, word, and bit offset between the ground terminal's transmission and reception counters (fig. 19).

The null request orderwire contains a ground terminal source address but no usable information. The null orderwire is

transmitted during a ground terminal's assigned orderwire burst location when no connect/disconnect or power augmentation requests are necessary and when no status information has been requested (fig. 20).

Variable word count concept.—Understanding the two types of data bursts requires that the concept of a vwc and some internal workings of the ground terminal be explained. The ground terminal, as designed, will allow any user to operate at any rate from 1 to 200 Mbps. A FIFO array is used to control user data flow with the vwc regulating the FIFO fill level by word stuffing to prevent an overflow or underflow condition.

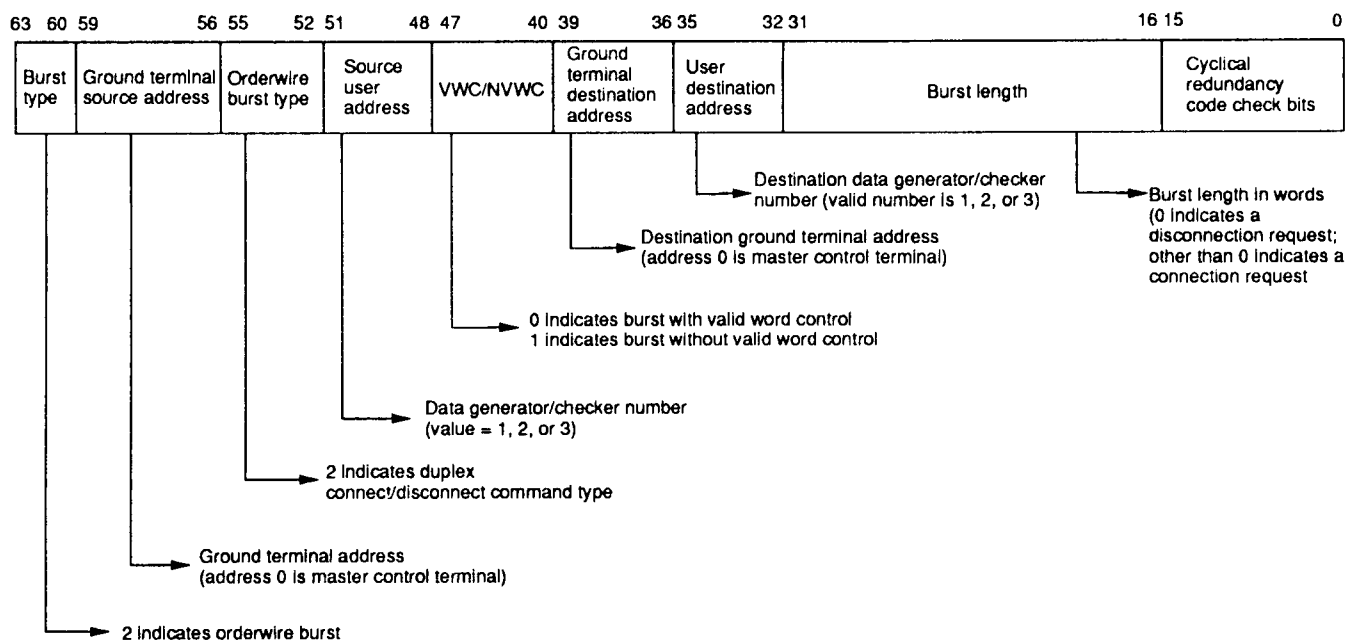


Figure 17.—Orderwire burst—duplex connect/disconnect type request.

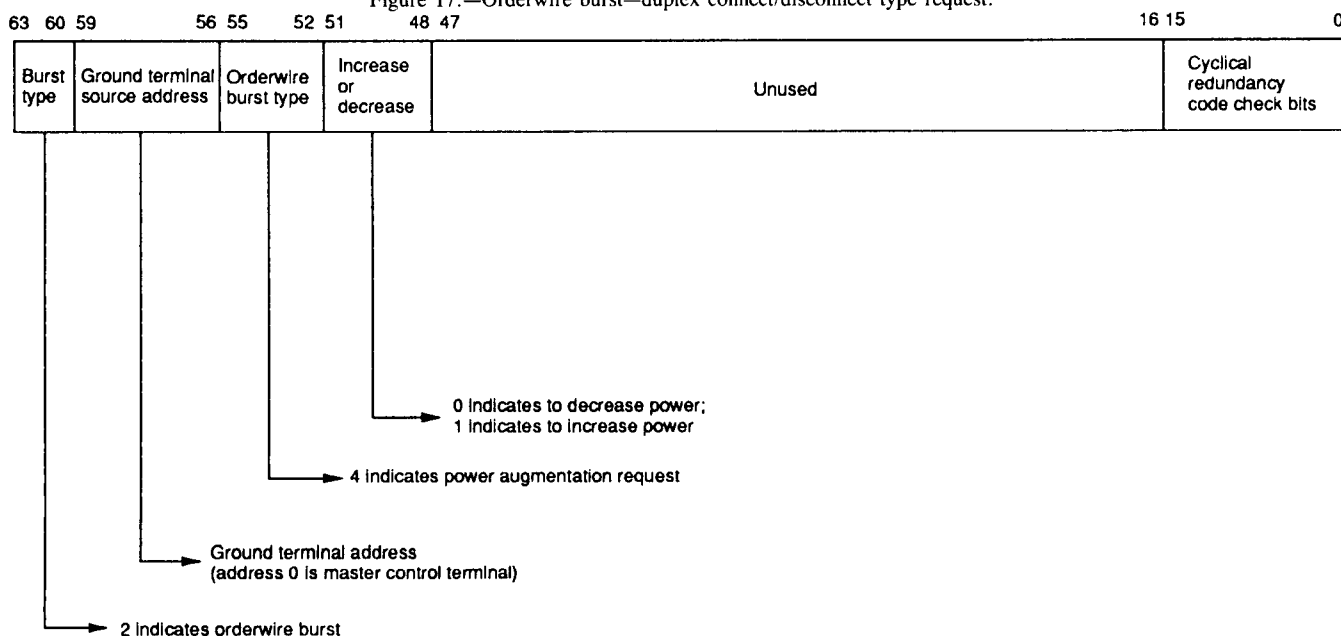


Figure 18.—Orderwire burst—power augmentation request.

The MCT always allocates an integer number of words per transmission burst request. For bursts using a vwc the MCT always allocates at least one word more of channel capacity than required. Bursts from users whose data rate is not a multiple of the burst rate must precede all data with a vwc field. This field contains information indicating one of four conditions:

- (1) The following $N + 1$ data words are valid.
- (2) The following N data words are valid.
- (3) The following $N - 1$ data words are valid.
- (4) None of the following data words are valid.

The receiving ground terminal reads the vwc and extracts only

valid words from the received data burst. Bursts from users whose data rate is an integer multiple of the burst rate do not require a vwc because the number of data words being transmitted will always be the same and all data words will be valid. Figure 21 shows an example of a vwc data burst having a user data throughput rate of 25 MHz. Table II shows various user data rates and their required burst lengths.

Data bursts.—There are two types of data bursts: bursts that contain a vwc, and bursts that do not contain a vwc (fig. 22). Data bursts may be located anywhere in the frame according to the MCT's burst time plan. The first four words of the data burst are preamble. When no vwc is required, the preamble

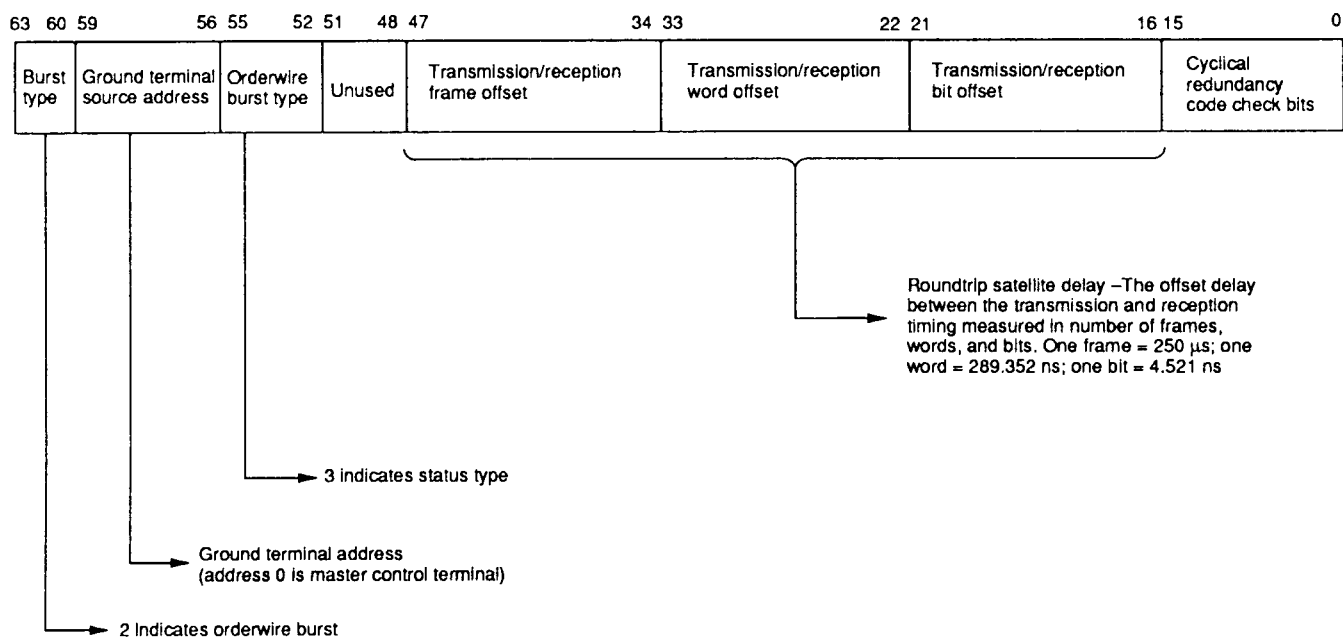


Figure 19.—Orderwire burst—transmission/reception offset status.

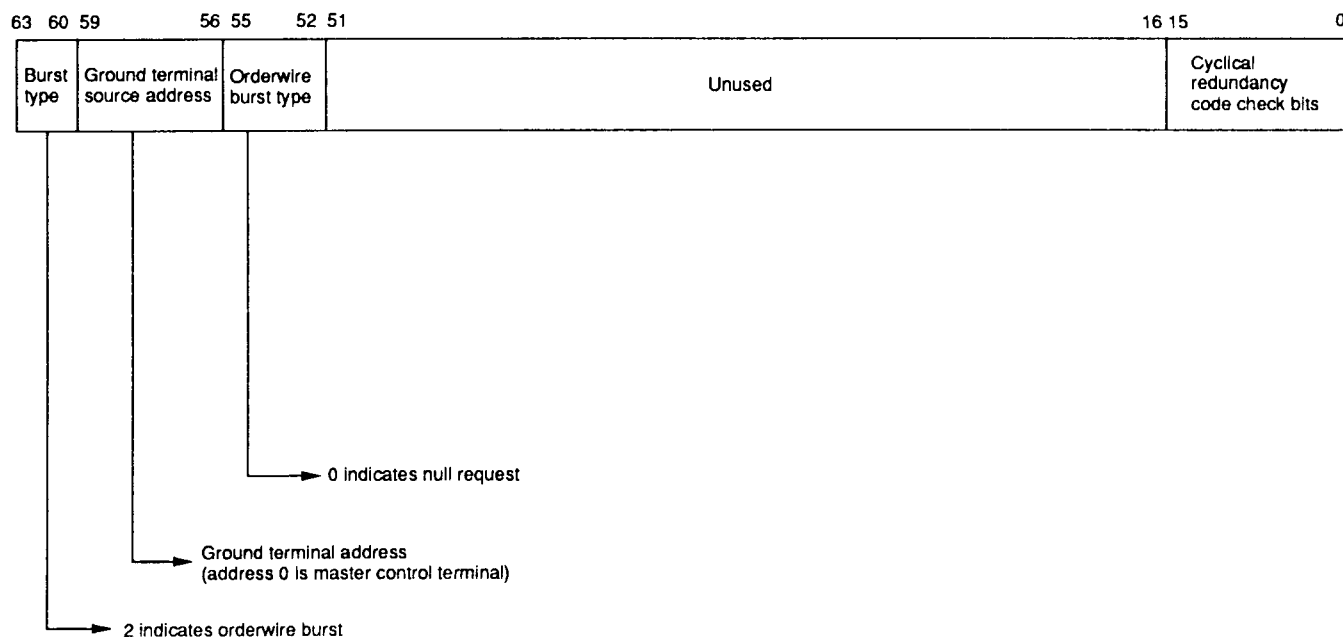


Figure 20.—Orderwire burst—null request.

is immediately followed by a predetermined number of data words. For a burst requiring a vwc the preamble is followed by a one-word vwc field that indicates how many of the following data words are valid.

Acquisition and Tracking

Acquisition and tracking are two of the most important functions that the ground terminals must perform in any TDMA

environment. Each ground terminal acquires and tracks (maintains synchronization with) the network timing such that its transmitted information reaches the satellite at precisely the moment that the matrix switch activates the predetermined communications link. A transmission that is sent too early will not be received by the destination ground terminal because the preamble will have reached the matrix switch before the channel was activated. Thus, the preamble will not be received and the demodulator will not lock onto the signal. A transmission that is sent too late may not be completely received

$$\frac{1 \text{ frame} \times (25 \times 10^6 \text{ bps}) \times (250 \times 10^{-6} \text{ s/frame})}{64 \text{ bits/word}} = 97.6 \text{ words}$$

Cannot send 97.6 words. Depending on the fill level of the first-in, first-out memory the valid word count will indicate that 98, 97, or 96 words are valid to prevent an over/underflow first-in, first-out memory condition.

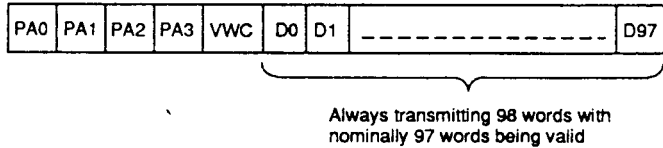


Figure 21.—Data burst with valid word count at 25 MHz.

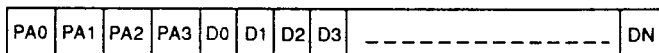
TABLE II.—DATA RATES SUPPORTED

(a) Burst with valid word count

| Data rate, Mbps | Words per frame | Burst length, words |
|-----------------|-----------------|-------------------------------|
| 1.25 | 4.8 | 5(DATA) + 4(PA) + 1(VWC) = 10 |
| 1.544 | 6.03 | 7 + 4 + 1 = 12 |
| 5.00 | 19.5 | 20 + 4 + 1 = 25 |
| 6.132 | 23.9 | 24 + 4 + 1 = 29 |
| 12.5 | 48.8 | 49 + 4 + 1 = 54 |
| 25 | 97.6 | 98 + 4 + 1 = 103 |
| 27.648 | 108 | 108 + 4 + 1 = 113 |
| 42.95 | 167.7 | 168 + 4 + 1 = 173 |
| 44.736 | 174.7 | 175 + 4 + 1 = 180 |
| 50 | 195.3 | 196 + 4 + 1 = 201 |
| 100 | 390.6 | 391 + 4 + 1 = 396 |
| 200 | 781.2 | 782 + 4 + 1 = 787 |

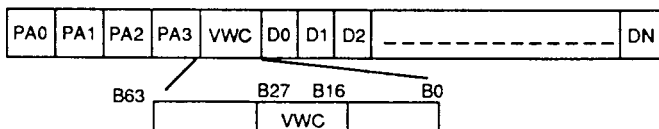
(b) Bursts without valid count word

| | | |
|---------|-----|-----------------------|
| 13.824 | 54 | 54(DATA) + 4(PA) = 58 |
| 27.648 | 108 | 108 + 4 = 112 |
| 55.296 | 216 | 216 + 4 = 220 |
| 110.592 | 432 | 432 + 4 = 436 |



- Located anywhere in frame
- Continuous throughput rate must be a multiple of the word rate

(a)



- One word for valid word count in which 12 bits are used
- Located anywhere in frame

(b)

(a) Data burst without valid word count.

(b) Data burst with valid word count.

Figure 22.—Data burst with and without valid word count.

because the trailing information did not pass through the communications link during the time that the matrix switch channel was active, causing a loss of data.

Any clock corrections must be performed with utmost certainty. Therefore, timing measurements will usually involve either a repetitive or an averaging process before a timing correction is made. Additionally, timing corrections cannot be made any faster than the roundtrip delay (approx. 250 ms for a satellite in geostationary orbit) or a potentially unstable control loop would result, where corrections are being implemented before the results of a previous correction are known.

MCT Acquisition

As stated previously, all network timing is ultimately referenced to the satellite matrix switch clock through the MCT. Therefore the MCT must synchronize its clock to the satellite matrix switch clock during initial satellite acquisition and tracking.

During initial acquisition the NCC via the MCT synchronizes the MCT frame and superframe timing with that of the satellite matrix switch by performing the following procedures: MCT loopback, MCT frame, and MCT superframe acquisition.

The MCT must first compensate for roundtrip path delay and satellite motion through MCT loopback acquisition. Initially, the matrix switch is open. The MCT continuously transmits reference bursts to itself. The MCT continuously monitors its reference burst while adjusting only its reception clock and reception superframe counter. When the reference burst has been properly received, the MCT loopback acquisition process is complete. At this point the difference between the transmission superframe and reception superframe counters is the total roundtrip path delay. The MCT loopback process continues to be performed in the background in order to compensate for satellite motion (range variation).

Once MCT loopback acquisition is complete, MCT frame acquisition begins. The NCC configures the matrix switch so that the MCT has a window to transmit through once per frame. The MCT transmits loopback metering bursts to itself. The metering burst consists of a preamble followed by a specified bit pattern. The MCT attempts to transmit the metering burst in the middle of the specified window. Upon reception of the metering burst, the NCC through the MCT examines the data to determine whether transmission was early or late. The NCC then commands the MCT to adjust its transmission and reception clocks accordingly. By adjusting both the MCT transmission and reception clocks, the MCT effectively shifts its frame timing relative to the satellite's frame timing. Initial acquisition using metering bursts continues until the required portion of the transmitted metering burst is received. At this point the MCT and satellite frames are aligned. The MCT metering process continues in the background in order to compensate for oscillator differences between the MCT and the satellite. Next, the MCT must acquire superframe timing.

Superframe timing acquisition is necessary for the following two reasons: First, the superframe is used to establish a reference point for all ground terminal transmission and reception frame counters. In the present system the beginning of the superframe is frame 1. Second, all ground terminal burst time plans and matrix switch reconfigurations occur on superframe boundaries.

The MCT acquires its superframe timing by using the following method: The matrix switch is reconfigured once every superframe such that the switch is opened during one superframe and closed during the next. Because the MCT knows its frames are aligned with the satellite frames, the MCT can transmit two known burst patterns, one pattern during each superframe. Since the switch is closed every other superframe, the MCT needs only to count the number of bursts of a specific pattern that were received. By subtracting the number of bursts received from the total number of bursts in a frame, the MCT will know how much and in what direction to adjust its transmission and reception frame counters. Once the MCT has acquired the satellite superframe timing, the matrix switch will be configured so that the MCT can broadcast a superframe reference burst to the traffic ground terminals once every superframe.

Once acquired to the satellite, the MCT must maintain bit, word, frame, and superframe synchronization to keep the network functioning. To maintain bit and word synchronization with the satellite, the MCT monitors its own transmitted reference burst to make the necessary corrections due to satellite motion.

To maintain frame synchronization with the satellite, the NCC monitors metering bursts to detect the drift of the MCT oscillator relative to the satellite oscillator. The MCT transmits to itself a metering burst during a specified time slot. The MCT passes the received data on to the NCC. These data will be used to determine the MCT oscillator drift relative to the satellite oscillator. The NCC then sends clock correction commands to the MCT to adjust the MCT transmission and reception timing.

To maintain superframe synchronization with the satellite, the NCC uses a synchronization method known as blink states. The NCC allocates a portion of the frame for loopback. This channel is active for every frame in the superframe except one, the blink state. The MCT loops back a predetermined burst once per frame. The frame in which the loopback message is not received is the superframe.

Traffic Ground Terminal Acquisition

During initial acquisition the traffic ground terminal systematically adjusts its reception word and frame counters to search for any reference burst in the frame. Once any reference burst is found, counter adjustments stop. The ground terminal identifies and interprets its reference burst. The traffic terminal continues to track the arrival of the reference burst, makes any necessary timing changes, and waits for a synchronization command from the MCT. Additionally, the

traffic terminal synchronizes its superframe timing by setting its superframe clock upon reception of the superframe reference burst. Although not implemented at this time and much less frame efficient, blink states may also be used for superframe synchronization. At this point the traffic terminal reception timing is synchronized.

Once the reference burst synchronization command containing the estimated roundtrip satellite delay and loopback burst location is received, transmission synchronization begins. The traffic terminal offsets its transmission clock from its reception clock according to the MCT's estimated satellite roundtrip delay and begins transmitting orderwire messages that are looped back to itself. The traffic terminal monitors its loopback orderwire and adjusts the transmission timing until the burst is received in the proper location. The traffic terminal is capable of adjusting its transmission burst timing over plus or minus two words. Therefore, the estimated roundtrip delay must be accurate to plus or minus two words (± 578 ns). If the traffic terminal cannot receive its own loopback bursts correctly, the complete traffic terminal acquisition process is reinitiated. The traffic terminal transmission will be synchronized after receiving its own loopback bursts correctly, and adjustments will stop. The traffic terminal is now completely synchronized to itself and the network.

After initial acquisition all traffic terminals continuously track the satellite timing. Each traffic terminal monitors the arrival of the reference bursts and makes any necessary adjustments to its reception timing. Each traffic terminal also monitors the arrival of its loopback orderwire burst and makes appropriate adjustments to its transmission timing.

Once the MCT and the traffic terminals have acquired network timing, the network should be completely synchronized and data transmission may begin.

Network Experiments Plan

The objectives of the experiments are to demonstrate and evaluate the overall network operation, rain fade/power augmentation, and various network routing algorithms. The following parameters may be varied during any of the experiments: signal-to-noise ratio, ground terminal transmission burst density,⁴ ground terminal reception burst density,⁵ network traffic density,⁶ matrix switch reconfiguration rate, range delay, range variation rate, and the rate and amount of rain fade. In addition to the previously mentioned parameters, the following parameters may be monitored during any experiment: ground terminal acquisition time, loss of synchronization time, and the BER through any communications channel.

⁴The amount of data passing through the modulator during one frame.

⁵The amount of data passing through the demodulator during one frame.

⁶The amount of data passing through the satellite matrix switch during one frame.

The experiments are separated into three categories, each successive category providing an additional magnitude of complexity: single-terminal, two-terminal, and three-terminal experiments. The single-terminal experiments involve the MCT communicating with itself. These experiments will evaluate the MCT's ability to acquire the satellite timing and to track the satellite motion. The two-terminal experiments will evaluate the ability of the MCT to bring another traffic ground terminal into the network as well as the ability to transmit and receive data between the traffic terminal and the MCT. This will be the first time long strings of data will be passed between two ground terminals having different system clocks: the MCT clock and the traffic ground terminal clock. The three-terminal experiments will be used to evaluate complete networking. One of the more significant experiments will be to transmit data between the two traffic terminals independently of the MCT. This will help determine the true degree of synchronism throughout the network.

The following types of experiments will be performed for each category: acquisition and tracking, range variation, and rain fade/power augmentation. Acquisition and tracking must be completed at the beginning of each experiment in order to bring the network up; therefore acquisition and tracking experiments will be performed first. Initially acquisition and tracking will be performed without range delay or range variation. The experiments will then be repeated with range delay and range variation to determine how well the ground terminals can synchronize to and track a moving satellite. Rain fade/power augmentation will initially be performed independently of acquisition or range variation. Range delay and variation will be added to the rain fade/power augmentation experiments in order to evaluate the ground terminals' ability to maintain network synchronization during rain fades. The power augmentation experiments will be restricted to a single downlink channel in the simulated transponder because only one downlink channel has a TWTA capable of operating at a variety of power levels.

Additionally, RF experiments such as adjacent and cochannel interference and burst-to-burst dynamic range variation will be performed. With the proper up/down conversion equipment, the remote RF channel can be combined with the second ground terminal to perform adjacent and cochannel interference experiments (fig. 6). Like the other experiments these experiments will be used to evaluate the ability of the ground terminal to maintain synchronism as well as to evaluate the BER performance of the link. The burst-to-burst dynamic range variation experiments will be used to evaluate the SMSK demodulator performance. The results will be useful for specifying and designing new modems, since the SMSK modems have yet to be evaluated in an actual network environment.

Concluding Remarks

A versatile experimental Ka-band network simulator has been implemented and is presently being used to demonstrate

and evaluate a three-terminal satellite-matrix-switched, time-division multiple access (SMS-TDMA) network. The system uses proof-of-concept radiofrequency hardware developed under NASA contracts and digital ground terminal and link simulation hardware developed in-house at Lewis.

This system provides many unique simulation capabilities such as range delay and range variation simulation and rain fade simulation. The range delay and range variation simulation capabilities will continue to help NASA gain a better understanding of the effects satellite motion has on acquisition and tracking for communications systems operating at high data burst rates (221.184 MHz). The rain fade simulation capability will continue to allow NASA to develop and evaluate methods for overcoming the dramatic rain attenuation characteristic at Ka band.

Computer control and monitoring of all radiofrequency and network parameters (e.g., signal-to-noise ratio, rain attenuation rate, and traffic density) will continue to allow experiments to be performed quickly and easily. This same computer is also being used to analyze and process the data.

Possible future modifications to this simulator include the addition of adaptive coding to compensate for rain fade, new ground terminal architectures, and new modulation formats (i.e., 16-CPFSK, 8-PSK, and 16-QAM) to improve bandwidth and power efficiencies.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, May 22, 1989

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Glossary

| | | | |
|-------|---|------|---|
| BER | bit error rate | NVWC | no valid word count |
| CPFSK | continuous-phase, frequency-shift key | PPU | power-processing unit |
| CRC | cyclic redundancy code | PSK | phase-shift key |
| DGCS | data generator/checker subsystem | QAM | quadrature amplitude modulation |
| DRAM | dynamic random-access memory | RDS | range delay simulator |
| DRP | digital routing processor | RF | radiofrequency |
| DS0 | digital system level zero | RFS | rain fade simulator |
| EC&M | experiment control and monitor | SITE | Systems Integration, Test, and Evaluation |
| FIFO | first-in, first-out | SMS | satellite matrix switched |
| GTUIC | ground terminal user interface controller | SMSK | serial minimum-shift key |
| HPA | high-power amplifier | S/N | signal-to-noise ratio |
| IF | intermediate frequency | TDMA | time-division multiple access |
| LNR | low-noise receiver | TT&C | telemetry, tracking, and control |
| MCT | master control terminal | TWTA | traveling-wave tube amplifier |
| MSC | matrix switch controller | VWC | valid word count |
| NCC | network control computer | | |

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| 16. Abstract A versatile experimental Ka-band network simulator has been implemented at the NASA Lewis Research Center to demonstrate and evaluate a satellite-matrix-switched, time-division-multiple-access (SMS-TDMA) network and to evaluate future digital ground terminals and radiofrequency (RF) components. The simulator was implemented by using proof-of-concept RF components developed under NASA contracts and digital ground terminal and link simulation hardware developed at Lewis. This simulator provides many unique capabilities such as satellite range delay and variation simulation and rain fade simulation. All network parameters (e.g., signal-to-noise ratio, satellite range variation rate, burst density, and rain fade) are controlled and monitored by a central computer. The simulator is presently configured as a three-ground-terminal SMS-TDMA network. | | | | | |
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